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Insight, part of a Special Feature on Holistic Solutions Based on Nature: Unlocking the Potential of Green and Blue Infrastructure

A context-sensitive systems approach for understanding and enabling ecosystem service realization in cities

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ABSTRACT. Understanding opportunities as well as constraints for people to benefit from and take care of urban nature is an important step toward more sustainable cities. In order to explore, engage, and enable strategies to improve urban quality of life, we combine a social-ecological-technological systems framework with a flexible methodological approach to urban studies. The framework focuses on context dependencies in the flow and distribution of ecosystem service benefits within cities. The shared conceptual system framework supports a clear positioning of individual cases and integration of multiple methods, while still allowing for flexibility for aligning with local circumstances and ensuring context-relevant knowledge. To illustrate this framework, we draw on insights from a set of exploratory case studies used to develop and test how the framework could guide research design and synthesis across multiple heterogeneous cases. Relying on transdisciplinary multi- and mixed methods research designs, our approach seeks to both enable within-case analyses and support and gradually build a cumulative understanding across cases and city contexts. Finally, we conclude by discussing key questions about green and blue infrastructure and its contributions to urban quality of life that the approach can help address, as well as remaining knowledge gaps both in our understanding of urban systems and of the methodological approaches we use to fill these gaps.

Key Words: *comparative studies; ecosystem services; green and blue infrastructure; institutions; perceptions; social-ecological-technological systems*

INTRODUCTION

Urban quality of life, across globally heterogeneous cities and in times of change and multiple pressures, presents a many-faceted challenge including both the maintenance of the quality of the urban landscapes and enabling fairly apportioned opportunities to make use of them. This article is grounded in an interest in the contribution by urban green and blue infrastructure (GBI) to human wellbeing, and how it is embedded in and dependent on urban social-ecological-technological systems (SETS) (e.g., Andersson et al. 2015*a*, Grimm et al. 2016, McPhearson et al. 2016, Depietri and McPhearson 2017). In different ways, people are fundamentally involved in the (co-)production of ecosystem services (ES) and even more so in the realization of various wellbeing benefits (e.g., Spangenberg et al. 2014, Palomo et al. 2016). There is a need to develop new practices for theorizing, empirically studying, and broadly and critically reflecting on both real-world diversity and complexity. Understanding opportunities as well as constraints for people to benefit from and take care of urban nature is an important step toward more sustainable cities, and the ambition of this paper is to move this understanding forward.

Frameworks and approaches for studying the interplay between the city, its residents, and ecosystems need to be sensitive and adaptable to local conditions, while still allowing for comparison across heterogeneous cities (Ward 2010, Robinson 2016, Wolff and Haase 2020). In this article, we present a conceptual systems-based framework for how to understand and study GBI and its benefits as embedded in urban systems. We discuss how this systems framework is operationalized by, and iteratively evolves with, a flexible, mixed and multi-methods approach for designing case studies. The framework is grounded in the philosophy of pragmatism (Maxcy 2003) and, as such, embraces a plurality of methods. It rests on the proposition that researchers should use the philosophical and/or methodological approach that works best for the particular research problem that is being investigated (Tashakkori and Teddlie 1998). Rather than a focus on methods, our framework puts the focus on the consequences of research and on the research questions. The framework is constructed to assess systemic barriers, enabling factors and contexts, and how they shape the flow and distribution of ES benefits to beneficiaries. In applications external to research, it may be used to guide the design and implementation of interventions both in the urban landscape and in its governance. The development of the conceptual framework and the research design presented in the paper are outcomes of a transdisciplinary deliberation process within the BiodivERsA funded project ENABLE[1], described in Box 1.

The paper begins with the "conceptualization" by presenting the framework and its roots, then moves to "operationalization" by outlining a set of guiding principles and questions for developing and positioning case studies. The guiding questions as well as the framework have been tested and developed through a number of

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explorative case studies, and we highlight some of these to illustrate a cumulative build-up of a more comprehensive understanding of GBI as embedded in urban SETS. Finally, we conclude by highlighting insights from the case studies and point to future avenues for continued refinement of the framework.

Box 1. The transdisciplinary deliberation process within ENABLE

The ENABLE project set out to improve our understanding about one main question: under what conditions does green and blue infrastructure (GBI) actually deliver benefits? ENABLE took a transdisciplinary approach to investigating the role GBI can play in tackling the social–ecological challenges facing cities, explicitly taking into account how these key aspects interact and influence the performance of green or blue infrastructure. Recognizing the unique character of place, location, and situation while still striving to elicit universally relevant knowledge, ENABLE invested in a transdisciplinary process for developing an approach for assessing and analyzing current conditions as well as scenarios of different futures. Central to all of the approach is the recognition of the importance of “context,” something that is often shunned as noise in science and research. The development of the conceptual systems model began with a causal loop diagram describing the most abstract level of the conceptual framework—at first, we did not have a shared language to describe the nuances of the effects the three systemic filters (infrastructures, institutions, and individual perceptions) could have on the realization of ES potential. Having identified the core model, we started a discussion of how to best study different aspects of filtering relative to ecosystem service flows, grounded in an interest in values, justice, and resilience (see Andersson et al. 2019 for an early version of the framework). Drawing on in-house transdisciplinary expertise, we first listed methods to capture specific filtering effects and then discussed how these methods could be modified to better connect to other aspects of the conceptual model. Based on this tentative portfolio of methods, we started to design the individual case studies, where we sought a match between our methods toolbox, local expertise, case-relevant versions of the generic research questions, and data availability. The ground-truthing through multiple case applications fed back both to discussions about methods and developing more integrated mixed methods designs, and about the conceptual framework itself. Case applications and their different needs had helped us develop a more sophisticated language and expanded theoretical foundation, and in parallel to working on causal loop models, we started to revise, refine, and describe the framework in words. A facilitated reflection process (Mascarenhas et al. 2021) further helped this step. Finally, with this article as an example, we have started to synthesize our studies and build a cumulative understanding within and across our six case-study cities (see Kronenberg et al. 2021, Andersson et al. 2021; M. Wolff, A. Mascarenhas, A. Haase, et al., *unpublished manuscript*).

CONCEPTUALIZATION

Systemic Mediation of Ecosystem Services Benefit Flows

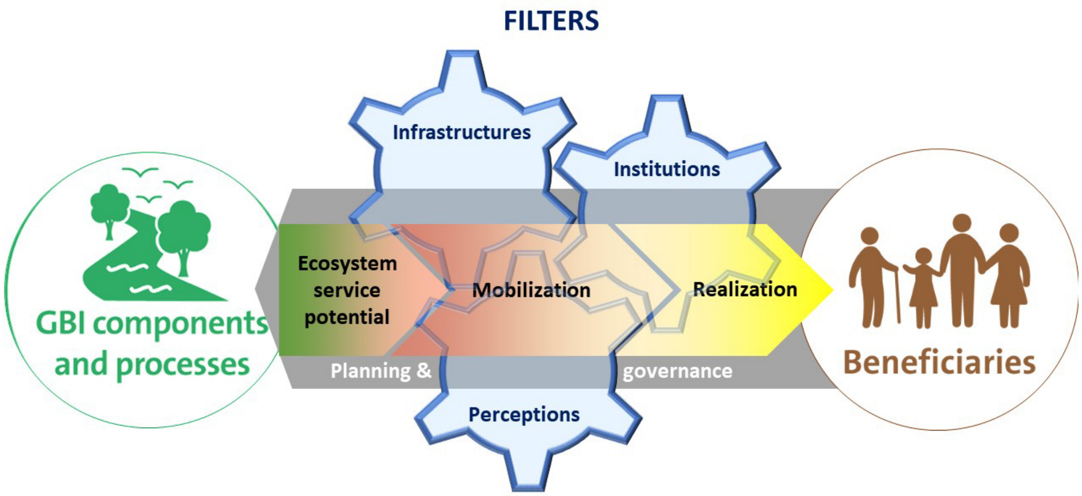
The core of our conceptualization is grounded in the emerging literature on the importance of people and contextual circumstances for the generation of ES benefits or nature’s contributions to people (e.g., Ernstson 2013, Spangenberg et al. 2014, Andersson et al. 2015*b*, Palomo et al. 2016, Díaz et al. 2018, Keeler et al. 2019, Langemeyer and Connolly 2020) (Table 1). Building on the adapted ES cascade model presented by Spangenberg et al. (2014), we focus on the three intermediate steps in a five-step sequence of generation and flow of ES benefits for developing our framework: ES potential, mobilization, and realization (explicitly leaving out the ecological properties of GBI and the valuation of benefits, although these could easily be added to the framework). The quality of the GBI and values we attribute to it, which are strongly influenced by lifestyles and overall cultural and socioeconomic, as well as targeted, management of GBI, determine ES potential. Sociotechnical systems and interlinkages activate and make available—mobilize—the ES potential, for example, by providing transportation infrastructure or an institutional setting that allows for ES use. Finally, realization captures how individuals actively or passively perceive and make use of available options for realizing different benefits.

Table 1. A matrix for positioning individual cases based on which of the three filters (vertical) and which steps of the benefit flow (horizontal) they focused on. The content of the cells indicates questions and issues that can be addressed and connected through the three filters framework.

	Potential	Mobilization	Realization
Infrastructures	Environmental problems, added value(s) of combining GBI with gray infrastructure	Integration of GBI with gray infrastructure (urban morphology), transportation, physical assets/ facilities	Mobility impairment, space syntax, mobility patterns
Institutions	Property right/ land use regimes, policy targets and goals	Access and use rights and regulations (formal and informal), facilitated activities	Compliance with regulations, appropriation, user conflicts
Perceptions	Value recognition, value formation, value articulation, ecological literacy	Sense of place, identity, programming, public participation	Affordances, legibility, stewardship, appraisal and preferences (ecological and social)

The generation of ES benefits is embedded in and dependent on the urban system. Our system framework and general philosophy is grounded in complexity theory, which provides the basis for our understanding of how interactions among multiple agents and processes can generate patterns, ordered structures, and emergence. Social, ecological, and technological transitions in

Fig. 1. Three systemic filters—infrastructures, institutions, and individual perceptions—shape the three steps (ecosystem service (ES) potential, mobilization, and realization) in the flow benefits from urban green and blue infrastructure (GBI) to beneficiaries, and hence, the final distribution of benefits. The filters represent core properties of the urban social-ecological-technological system (SETS), which means that people are connected to them through multiple linkages/relations and not just through the flow of ES benefits. People, beneficiaries, and society in general are actively interacting with and changing GBI, as well as the filters, and thus in turn, directly or indirectly, the flow and distribution of benefits.



complex systems pose challenges to system stability and resilience but are also important sources of novelty and transformation (Alberti et al. 2018). We view cities as nested, non-equilibrium systems (Krugman 1993, 1998, Batty 2005, McHale et al. 2015), where dynamics and different outcomes emerge from complex interactions that take place at and across several scales (Batten 2001, Walloth 2016). This means that the effects and interactions among components may be indeterminate because of complexity effects and probabilistic causal mechanisms, and that generalizability will always need to be balanced with locally specific and unique details. Combining a system articulation in line with the growing literature on social-ecological-technological systems (SETS) conceptualizations (Ramaswami et al. 2012, Andersson et al. 2014, Depietri and McPhearson 2017, Keeler et al. 2019, McPhearson et al. 2021) with assemblage theory (e.g., McFarlane 2011, DeLanda 2019) and urban theorizing (e.g., Ernstson et al. 2010, Robinson 2016), our framework provides an ontological and epistemological structure that can accommodate and connect different scientific traditions. Inspired partly by comparative urbanism (sensu Robinson 2016), it is "open to conceptual revision, and offers methodological and philosophical grounds for a new repertoire of comparative methods open to 'thinking with elsewhere'." (ibid: 188).

Consistent with Andersson et al. (2019), we position the three steps of ES benefit realization as dependent on the social, ecological, and technological circumstances. These include the quality and distribution of GBI itself, and further mediated by three system-level factors, in this article referred to as filters: infrastructure (composition and configuration of the urban landscape and its green, gray, and blue infrastructures), institutions (rules and norms, formal and informal), and the capacities and individual perceptions of different actors. The three filters frame the flow of ES benefits by mediating how ES are generated as well as to whom their benefits are available (Fig. 1). Infrastructure is highly relevant for connecting ES generation and demand, and it has multiple additional functional linkages to ES and GBI (hybrid gray–green infrastructure, land appropriation, environmental impacts, etc.) (e.g., Grimm et al. 2016, Depietri and McPhearson 2017). The importance of institutions for framing the use and governance of natural resources and not least the distribution of ES benefits is widely recognized (e.g., Ostrom 1999, 2009), making them highly relevant for understanding the generation of ES and realization of ES benefits (see also, e.g., Webster 2002, 2007, Colding and Barthel 2013). Finally, we hold perceptions to be the basis for final realization of benefits (e.g., Pierskalla and Lee 1998, Chemero 2003, Spangenberg et al. 2014, Chan et al. 2016, Raymond et al. 2017). Under perceptions, we include both urban residents' appraisal (including value attribution, agency in the sense of recognition of opportunities offered by the combined GBI, infrastructure, and institutions) of and capacity (based on multiple individual factors such as age, education, preferences, socioeconomic circumstances, etc.) to use the system.

Inherently Different Ecosystem Services

Depending on the type of ES (regulating, cultural, supporting, or provisioning (see, e.g., Gómez-Baggethun et al. 2013), all have their differences in terms of ecological requirements, mobilization, and realization), the filters can enable or restrain ES benefit flows in multiple ways. For example, over the longer term, urban morphology (built infrastructures and overall land use composition and configuration) together with institutions (planning legislation and governance, ownership, etc.) and people's interest and engagement decide the management and overall development of GBI (e.g., Pauleit et al. 2019*b*), which is a fundamental precondition for ES generation and distribution. The process of mobilizing and then realizing different benefits from existing GBI partly intersects with the filters in other ways. For benefits to accrue from local climate regulation, for example, the integration of GBI and gray infrastructures is critical—e.g., to cool down residential areas, GBI must be close (Hamstead et al. 2016, Keeler et al. 2019; Andersson et al. 2020), and to offer people cool outdoor environments, GBI must be easily and locally accessible (e.g., connected to public transportation or cycle paths). Here, linkages between areas of supply and demand are essential (Fisher et al. 2009, Syrbe and Walz 2012). Other ES benefits have an even stronger element of human involvement in their realization. Recreational wellbeing benefits, for example, require physical and institutional access to suitable spaces, quite often auxiliary mobilizing infrastructure like benches, toilets, and barbeque areas. They also need individuals capable of recognizing and interested in using these opportunities and thus realizing associated benefits (Spangenberg et al. 2014, Łaszkiewicz et al. 2020), the latter influenced not least by perceptions of and interactions with other users and uses (e.g., Low 2013). Each filter is understood as having both direct, individual effects, and a combined interactive effect on the flow and distribution of benefits. The filters framework can be applied to aggregate bundles of ES (e.g., recreational services), multiple more autonomous ES (e.g., the range of services of interest to a specific user group) or individual ES. Regardless of which, it is relevant for any or all steps of ES potential, mobilization, and realization.

OPERATIONALIZATION

Bringing together diverse ES benefit flows and understanding the combined effects of the filters arguably benefit from inter- or transdisciplinary approaches (see Berkes and Folke 1998, Turnhout 2019 for definitions). These can "(a) grasp the complexity of problems by coming from different access roads, (b) take into account the diversity of scientific and life–world perceptions of problems, (c) link abstract and case-specific knowledge, and (d) develop knowledge and practices that promote what is perceived to be the common good" (Pohl and Hadorn 2007:20).

With this as the rationale, we have operationalized and developed the three filters framework through a flexible, abductive, mixed-methods approach that draws on insights from a number of case studies exploring the conceptual framework and its different aspects, some of them described in the next section (see also Append. 1). Although further development is needed, especially concerning case comparison, we argue that the framework holds the potential to promote outcomes that can be used to cumulatively build an understanding of a specific case (e.g., city district or region) and for comparing across cities and across methodological differences.

Our case studies iterate from the explorative application of the framework and gathering of information toward a structured description of the focal issue and case-specific version of the conceptual framework. In most cases, abduction, based on the first information gathered, led to hypotheses concerning the most relevant filter components and guiding rules in the situation under study. These hypotheses in turn informed the more structured search for evidence supporting or refuting the hypotheses. This iteration meant that knowledge about case contexts and specific issues was built in parallel with empirical evidence supporting its description, which in turn was used to theorize back and further develop the conceptual framework.

Developing, Positioning, and Learning from Case Studies

Contextual circumstances imply a need for case-specific designs and applications of the conceptual framework. The ambition with the approach described here is that it should be capable of both providing actionable knowledge relevant to the case, as well as insights for critically engaging with either the conceptual framework itself, or the implications of the study (e.g., are ES benefits fairly distributed, or is the provisioning resilient?). Grounded in the shared conceptual framework, each case had its specific research questions including specifications of which ES and which filters were in focus, how the filters manifested, nature of the filter effect, and the outcomes (i.e., reducing or magnifying benefit flows or changing the distribution of benefits). For each case, the methodological design and later results were assessed and adapted through a stepwise approach (for guiding questions for each step, see Append. 1):

1. Deciding on the case-specific research questions that would contribute to both scientific knowledge and case-specific needs (ENABLE used expert assessment, desktop study, and/or stakeholder consultation).
2. Data collection and analysis (in ENABLE, choices of methods were grounded in literature, own expertise, and secondary data, and project workshops focused on interdisciplinary epistemological assessment and discussion).
3. Evaluation (within ENABLE, we used technical or scientific assessment, and/or stakeholder dialogs and knowledge co-creation).

The next section will describe in more detail how different targeted case studies have supported the development and operationalization of the three filters framework.

Explorative Case Applications and Insights

The ENABLE project worked in six different cities and had multiple cases in each city. In the following section, we have selected six cases, one from each city, to illustrate the development and application of the three filters framework. These cases, together with several others presented in this special feature, provide the foundation for both insights on how the filters work and can be studied, and for identifying remaining challenges that future research will need to address to advance comparative, transdisciplinary urban studies (Append. 1). The cases do not necessarily focus on the filters explicitly, but the filter approach is built into them, and we focus on how they were. Thus, none of the cases represents all aspects of the approach; what they offer is individual contributions to the overall understanding of a specific city, as well as of the systemic filtering of GBI benefits (Table 2).

Barcelona

Case context: The City of Barcelona is extremely compact, with low levels of green space per capita compared with other European cities. The city's goal is to increase GBI by 1 m² per inhabitant until 2030 to enhance equality in people's access to GBI benefits. Given the limited space and resources, the overall challenge was to identify locations, for effectively and fairly establishing multi-functional GBI, and thus address pressing challenges such as the lack of recreational opportunities and vulnerabilities to heatwave events. Barcelona has extensive geographic assessments and a sophisticated understanding of spatial inequalities in social–ecological needs and vulnerabilities. However, these have neither been incorporated into holistic, integrated assessment frameworks, nor related with GBI capacities to mitigate them.

Table 2. Types of filter effects demonstrated in the six ENABLE cases.

Physical	Procedural	Mental
Movement (access), available assets/ facilities (what activities), technical constraints (interventions), rights	Governance/planning (processes, practice), legal constraints (interventions, use, management)	Attractiveness of site and setting (activities, times, actors), awareness/ knowledge (activities, access, actors)

Research question: Where could new GBI (green roofs) be established to ameliorate injustices in access to benefits?

Which ES and where in the flow: The study explicitly addressed six ES that were considered most relevant in the study context (Langemeyer and Baró, *unpublished manuscript*): thermal regulation (micro and regional climate regulation), stormwater runoff control, habitats for pollinators, food production, recreational opportunities, and the facilitation of social cohesion. The primary focus was on GBI itself and, to some extent, ES mobilization based on the existing integration of GBI and gray infrastructure and how it could be remediated through GBI planning. In this particular case, through the implementation of different green roof types, whereas realization and potential played minor roles (e.g., Langemeyer et al. 2020, Langemeyer and Baró, *unpublished manuscript*).

Filter focus and filtering effect: The study primarily focused on infrastructure (physical and institutional constraints to where GBI could be grafted to gray infrastructure), whereas perceptions played a subordinated role for the feasibility of GBI implementation. The study approach builds on a combined theoretical foundation of spatial ES justice (Langemeyer and Connolly 2020), and social–ecological urban resilience and vulnerability theory (Hamstead et al. 2016, Herreros-Cantis et al. 2020).

Study design: The study used a sequential approach informed by (participatory) multi-criteria decision analysis (MCDA) of ES (Langemeyer et al. 2016, 2018) and graphical Bayesian Belief Networks (BBNs) (Nielsen and Jensen 2009, Chen and Pollino 2012). The combination offered a way to combine different quantitative data streams (spatial ES needs models) with qualitative expert opinions (ES priorities and GBI capacity estimations) into an integrated, spatially explicit decision support framework. The underlying spatially explicit ES needs and social–ecological vulnerability models were developed based on secondary data available in the city of Barcelona, and examined the spatial inequality in needs and vulnerabilities relating the urban infrastructure to the demographic profile of the population (GIS approach). The prioritization of ES and GBI capacity estimations were obtained through deliberative group exercises in order to determine which ES were most needed, and to estimate GBI capacities to provide ES (expert workshop). To inform GBI planning, all information was integrated within a spatially explicit evaluation framework regarding how to effectively match ES demand and provision (coupled MCDA-BBN model).

Extensions and connections: The Barcelona approach was closely tailored to the city's decision-making needs and processes. It is flexible in how it combines secondary, qualitative data streams, where available, with expert knowledge to fill existing data gaps. Furthermore, it highlights important institutional conditions as entry points for spatially equitable GBI planning and ES provision (Langemeyer and Connolly 2020), jointly considering infrastructure deficits and social–ecological vulnerabilities.

Halle

Case context: Halle GBI and its potential ES are under pressure from drivers such as an increasing population (since 2011), met by urban densification and land consumption within the inner city, and climate change effects, such as occasional flooding. The initial assumption was that a case-specific combination of the filters would reveal multi-dimensional barriers that influence the accessibility to recreational benefits by residents. Consequently, the overarching goal was to sensitize GBI planning strategies to the role barriers play for equitable access to GBI benefits, and hence support neighborhood-to-city initiatives aiming to increase accessibility.

Research question: In what ways do the filters create barriers for recreational use of GBI?

Which ES and where in the flow: Using GBI as a proxy for recreational opportunity, the primary focus was on mobilization and, to some extent, realization of recreational ES and their related benefits.

Filter focus and filtering effect: Filters were framed as barriers to movement and restrictions on the use of GBI. At the site level, filters were studied as physical and perceptual barriers at the site or in the surroundings (following Brown and Raymond 2014 and Wolff and Haase 2020). Then, filtering effects were assessed in terms of altered use patterns relative to changes in the urban morphology (integration of GBI and gray infrastructure at the city level). Finally, additional perceptual aspects of the barriers were studied through user perspectives on multiple human (recreational) activities and conflicting interests.

Study design: In order to develop an integrated understanding of all three filters in relation to barrier effects, a combination of quantitative and qualitative assessments of spatial correlations between multiple barriers and their combined effects was used. To capture the infrastructural filter, we mapped physical barriers to GBI using a GIS model and publicly available data (Barber et al., *unpublished manuscript*). A mental mapping exercise captured perceptual barriers hindering especially marginalized people from using GBI (D. Haase, L. Drukewitz, M. Wolff, *unpublished manuscript*). Through a series of expert interviews, the institutional filter barrier effects through GBI infrastructure planning and management were identified. As a last step, continuous dialogs with stakeholders scoping out intervention options for identifying and overcoming barriers were performed. Questions were sequenced as follows: (a) What are the geographical patterns of physical barriers? (b) What are the main institutional barriers to green space planning, management, and use? (c) What are patterns of recreational use of GBI and thus access to the benefits?

Extensions and connections: The combination of both spatial and mental mapping allowed an integration of the infrastructural and the perceptual filter at least applied to a single neighborhood. The integration of the institutional barriers was not (yet) reached, mainly because of the lack of spatial information. The study provided a starting point for stakeholder workshops at the end of the project aimed at identifying intervention opportunities under current planning and governance practice, explicitly including local, grassroots initiatives.

Lodz

Case context: One of the key problems with GBI in Lodz is the large discrepancy between what is officially considered green space (accounting for around 13% of the city's area) and the much larger share of the city area covered by vegetation, but not officially recognized as green space (≥70%) (Feltynowski et al. 2018, Sikorska et al. 2020). In light of this discrepancy, any decisions regarding the changes of the latter type of green spaces will dramatically influence the provision of ES and benefits. Therefore, it is of great importance to describe the current state of GBI potential to provide ES and to identify where formal recognition of GBI components are most needed and where the current ones fail to meet the needs and demands of their potential users.

Research question: What groups of inhabitants are unprivileged in terms of ES provision, and how do the main barriers influence the flow of ES benefits?

Which ES and where in the flow: The focus was on GBI as a proxy for a bundle of experiential ES, i.e., services that require physical access, primarily various recreational activities. The primary focus was on mobilization, with realization and ES potential included in terms of what GBI users perceived as attractive for different recreational uses.

Filter focus and filtering effect: Institutions were positioned as the key filter, influencing both infrastructure and preferences—formally and informally (see, e.g., Anderies et al. 2016). With this as the starting point, filtering was conceptualized as insufficient/limited availability of GBI (integration and layout of GBI and gray infrastructure), barriers preventing access to GBI (primarily different use rights and other institutional barriers, along with some physical barriers), and/or its limited attractiveness (representing one aspect of the perceptual filter) (Biernacka and Kronenberg 2018).

Study design: The investigation included a mix of methods (policy document analysis, including legal documents, regulations, local zoning plans, publicly available maps; descriptive analysis of examples of restricted availability/accessibility/attractiveness; interviews; spatial mapping and analysis) performed consecutively. Questions and methods were organized as follows: (a) How do availability, accessibility, and attractiveness affect the delivery of benefits from GBI? (analysis of various policy documents); (b) Which institutional conditions restrict or prevent the use of GBI at all three levels (availability, accessibility, and attractiveness)? (descriptive analysis of selected examples where restricted availability, accessibility, and attractiveness of selected GBI components affected the delivery of different ES); and (c) What is the spatial distribution of these barriers? (spatial mapping and analysis).

Extensions and connections: The Lodz framework and design provide input to a discussion about distributional justice. Developed and tested in Lodz, the framework can be adapted to other case-study contexts. Although used principally to assess barriers preventing GBI/ES provision, the barriers are but one side of the filters and the framework that can be used to study other enabling factors as well. Several spin-off studies were carried out, such as the map of attractiveness of specific components of GBI in Lodz (Łaszkiewicz et al. 2020) and the analysis of GBI accessibility and attractiveness to specific disadvantaged groups (Koprowska et al. 2020).

New York City (NYC)

Case context: The use of GBI as a nature-based solution toward climate change has become mainstream in NYC. Planting trees, increasing the presence of green roofs, and deploying green infrastructure for stormwater retention are examples of GBI implementation by the city. Previous work has focused on mapping the current distribution of GBI benefits within the city in order to identify areas where ES are more or less abundant (Kremer et al. 2016). This mapping of GBI benefits supply, however, fails to inform where they are actually needed (ES demand) in relation to the distribution of environmental risks. In addition, the city presents legacies of segregation and environmental injustice that might translate into an unequal distribution of benefits provided by GBI.

Research question: How does the GBI–gray infrastructure configuration match demand for GBI benefits across space?

Which ES and where in the flow: Three regulating services are of high relevance in climate change adaptation (local temperature regulation, storm water mitigation, air purification). The study focused on ES potential by mapping ES supply through process-based modeling, and on their mobilization by assessing their distribution across the city's blocks. Realization was addressed through risk, exposure, and structural injustice (manifested as personal constraints) on the demand side.

Filter focus and filtering effect: The study focused on the infrastructure filter by relying on GIS mapping methods to assess the spatial distribution and integration of GBI in the sense of distance between supply and demand. Demand was connected to both institutional and individual factors (socioeconomic circumstances, etc.). The conceptual frameworks of mapping supply and demand for ES were based on Burkhard et al. (2012, 2014). The supply of GBI benefits was carried out relying on the work by Kremer et al. (2016). To map demand for GBI benefits, we defined demand as "need for risk reduction" as suggested by Wolff et al. (2015).

Study design: The study mapped the mismatch between demand and supply of GBI benefits by processing spatial, social, and ecological data to generate comparable, normalized indicators that relied on governmental thresholds to define different demand levels. It then created a combined supply–demand mismatch index (Herreros-Cantis and McPhearson, *unpublished manuscript*). Questions and methods were organized as follows: (a) How does the supply of GBI benefits vary across the city? (spatial analysis - ecosystem services modeling); (b) How does the exposure and magnitude of each environmental hazard vary across the city? (spatial analysis - risk mapping); (c) How is the demand for GBI benefits differently met across the city? (spatial analysis); and (d) What are the average income and proportion of communities of color in areas with different mismatch levels? (spatial analysis - descriptive statistics).

Extensions and connections: The study provides an important addition to the conversation in NYC regarding GBI planning for distributional justice by adding the missing question of where are benefits needed, in addition to where are benefits currently being provided. The methods developed aim to be replicated in other cities due to the relatively low data requirements and their adaptability to context-specific needs (e.g., by setting different thresholds for demand based on local policies or criteria).

Oslo

Case context: Although average availability of green space in Oslo's built zone at 60 m² per inhabitant is relatively high, inner-city availability is gradually decreasing, and user density is increasing. Between 2013–2017, Oslo's population increased by 7%, with formally managed greenspace increasing by 4%, whereas actual green cover, including trees in public streets and squares, decreased by 3% (Oslo kommune 2018). Traditional recreation potential mapping underestimates the importance of infrastructure qualities and configuration for use.

Research question: What qualities of urban open spaces increase recreation realization and is there a “green refuge” effect magnifying the importance of these qualities during Covid-19 lockdown measures?

Which ES and where in the flow: The target ES was outdoor recreation activities. The study investigated primarily mobilization and realization.

Filter focus and filtering effect: Enabling filters focused on perception as revealed by recreation activity correlations with normalized difference vegetation index (NDVI), tree canopy, path density, and population density, differentiating recreation response to these qualities by pedestrians and cyclists. The institutional filters of relevance include everyman's access rights to greenspaces; Covid-19 mobility restrictions and social distancing requirements specific to Oslo municipality. Infrastructure modeled included 7000 km of paths in open spaces in Oslo municipality. A main finding of the filtering effect is that already existing pedestrian and cyclists' preferences for green views and tree canopy increased during the lockdown, and preferences for low trail density were expressed, in line with expectations about social distancing needs. The study approach builds on the theoretical foundations of mapping of green space availability, accessibility, and attractiveness and actual delivery using mobility data (Zulian et al. 2018, Biernacka and Kronenberg 2019, Havinga et al. 2020).

Study design: Recreation availability, accessibility, and attractiveness were initially modeled using network distance to remotely sensed physical landscape qualities (Suárez et al. 2020). Remotely sensed and classified vegetation cover was explored to explain patterns of actual pedestrian and cycling use of locations and site qualities as observed in mobility data (Venter et al. 2020). The same data were used to test whether actual mobility patterns could confirm green view and tree canopy recreation model assumptions. Additional explanatory power was attained by quantifying attractiveness of greenspaces before and after Covid-19 mobility restrictions. Questions and methods were organized as follows: (a) Do standard methods of mapping recreation potential of greenspace in a baseline situation as analyzed in ENABLE reflect recreation use during a time of crisis, as represented by mobility restrictions during pandemic? (spatial analysis of mobility data); (b) What is the relative importance of open spaces during the baseline compared with Covid-19 mobility restrictions? (recreation model); and (c) What greenspace qualities are potential vs. actual indicators of recreation preference in baseline and crisis situations? (analysis of user data in relation to greenspace condition variables).

Extensions and connections: The comparison of results revealed an increased importance of locally available greenspaces in both inner city and greenbelt during the pandemic, with an attraction to greenness, tree canopy cover, and low path density, which was stronger in pedestrians than cyclists. It showed that the relative importance of green open spaces in the inner city is underestimated in the baseline recreation potential mapping approach. The results have been used to suggest improvements to municipal mapping and valuation of outdoor recreation.

Stockholm

Case context: The entry point for the Stockholm case was a strong policy attention to access to GBI benefits, with a special focus on formally protected spaces within GBI. Despite an openness to adapt/transform the approach to GBI, sectoral disconnects in the governance create barriers to such changes. Stockholm has a rich baseline mapping of GBI and discussion about recreational opportunities, as well as other ES. Although in certain ways rich (policy priorities, maps, social values, etc.), the material tends to focus on where people do things or see value, not why. In addition, the information and intentions in planning and management are spread out across policy spheres with limited connections and alignment (e.g., Enqvist et al., *unpublished manuscript*).

Research question: Which filters are necessary for the realization of benefits from nature-based recreational activities?

Which ES and where in the flow: Multiple recreational services. The primary focus was on ES mobilization, i.e., how the GBI potential for different recreational benefits is augmented by additional features like footpaths, access rights, or guides. Ecosystem services potential and realization were addressed to a more limited extent.

Filter focus and filtering effect: Benefits and filters were connected through an analytical framework based on recreational activities (leading to benefits) and their prerequisites (elements and aspects from the three filters, e.g., different facilities, equipment, information, regulations) (Borgström et al., 2021). The three filters were used as codes for classifying the preconditions needed to pursue different recreational activities and filtering assessed as the presence, absence, or degree of preconditions at scales relevant to the activities. The study approach was grounded in theories on ES co-creation (e.g., Spangenberg et al. 2014, Palomo et al. 2016), recreation studies (e.g., Virden and Knopf 1989), and accessibility studies (e.g., Casas 2007, Ala-Hulkko et al. 2016). The study was explorative and had no predefined special focus on any of the three filters.

Study design: The investigation included a partly sequential, but mostly parallel multi-methods approach, where the next step was to some extent informed by the previous one. The case focused primarily on the users' perspectives (and hence grounded in the perception filter). With no pre-existing detailed analytical framework (the preconditions), and, later, no readily available secondary data on all the preconditions, primarily qualitative methods and analyses were used. Questions and methods were organized as follows: (a) What are identified as key preconditions for GBI-based recreational activities according to different actor groups? (focus group dialogs); (b) Where are the valued GBI components located according to residents? (mental mapping); (c) What are residents' perceptions of accessibility and barriers to GBI benefits? (focus group dialogs, mental mapping); (d) How are recreation and biodiversity addressed, directly and indirectly, in local policies? (policy analysis); and (e) How are the preconditions influenced by change and how can they be addressed to enable flow of GBI benefits according to stakeholders? (participatory workshops, survey, interviews).

Extensions and connections: The study results provide a solid starting point for assessing and discussing differential opportunities to derive recreational ES benefits, both across space and across interests and groups (users, non-users). By breaking down the three filters to different preconditions and using recreational activities as a logic for connecting these, it also offers ways to bridge sectoral fragmentation and divides in urban landscape governance.

DISCUSSION

The conceptual model with flows of benefits from GBI framed by three system-level filters—infrastructure(s), institutions, and the perceptions (together with related abilities, capacities, and preferences) of urban residents—allowed for a shared baseline and reference framework for organizing and connecting different, primarily exploratory, methodological approaches across the six ENABLE cities. Green and blue infrastructure benefits, as well as filters, are fuzzy conceptual objects in the sense that they help crossing disciplinary and sectoral domains and provide individual cases with points of reference, rather than supporting a "standard" way of defining or studying different phenomena. This facilitated the development of a common language and more comprehensive critical evaluation of results (as argued by, e.g., Mollinga 2010). Thus, it allowed us to work toward the same goal without requiring strict consensus on a final definition, yet allowing for contextual richness in the form of filters (see, e.g., Brand and Jax 2007, Baggio et al. 2015). The connected and complementary research questions have allowed us to (1) move back and forth between empirical cases and the overall conceptualization, (2) deepen the overall understanding of how the three filters shape and guide the flow of GBI benefits, and (3) identify and provide output that could be readily used in practice to address wellbeing challenges and nature-based solutions to these.

Enabling or Constraining Circumstances?

As the cases demonstrate, the filters were, at the operational level, broken down into more specific factors and filter effects. These were held to be, or emerged as, especially relevant for the set of benefits under consideration, the aim and scope of the case study (e.g., a specific planning process or instrument, a specific spatial or temporal scale of understanding, the assessment of current (non-)use patterns, etc.), available information sources, and the local capacity to access them. We recognize two primary applications of the three filters approach: to understand current conditions and the opportunities they have to offer based on existing structures and processes, and to explore and inform long-term options for how to maintain or reshape the system to ensure both ES generation and equal opportunities to realize their benefits.

For the first, ES potential can be understood as supply, which needs to meet user needs and capacity to realize GBI benefits. User capacity to realize ES potential into benefits is embedded in the actual physical and institutional (here, primarily used in sense of regulated use of land (e.g., Dietz et al. 2008)) as well as in user needs (Vierikko et al. 2020) and perceptions. Perceptions relate to both ES potential and the overall options the system affords for realizing these (e.g., Chemero 2003, 2009). Hence, perception as we use it, is not limited to ES, or the perceived value of ES benefits, but extends to an overall appraisal of the place-based, infrastructural, institutional, and interpersonal context of realizing ES benefits (e.g., Kronenberg et al. 2021, Kraemer and Kabisch 2021, both in this Special Feature).

For the second, the filters approach can be extended to the process of changing the system over time. From this more temporal perspective, infrastructure and institutions are intervention tools (Cumming and Epstein 2020) and additional institutions regulating governance processes (procedures, instruments, planning legislation, etc.) together with the perceptions of potentially involved stakeholders frame the decision making (following Vatn (2005) for a broader definition of institutions). This second line of application is well suited to address questions about how to govern ES as embedded in a continuously changing SETS, understand use, or inform long-term governance and development. In this paper, we focused on the first application; for the second, we refer to Andersson et al. 2021, Borgström et al. 2021, and De Luca et al. 2021 in this Special Feature.

The relevance and operationalization of the filters framework, and how to best capture their influence, depend on which of the two aforementioned approaches you focus on. For example, institutional barriers to GBI use are diverse and range from restricted access rights to GBI to involvement in policy making (Biernacka and Kronenberg 2018, 2019; M. Wolff, A. Mascarenhas, A. Haase, et al., *unpublished manuscript*). Most, but not all, of our cases build on a beneficiary's view of the system. Our results from, e.g., Lodz, Halle, Stockholm, and Oslo show not only how people perceive and use GBI, but how they experience the overall context (including infrastructure, institutions, and other people present), and how GBI becomes an integrated part of a more comprehensive appraisal of the urban fabric.

Our explorations of the institutional and perceptual filters indicate that they play a bigger, complementary role in the use of GBI than is normally accounted for by spatial–physical indicators (e.g., distance to green spaces, per capita GBI ratio, or land use) often used in GBI modeling, mapping, planning, and management (Kabisch et al. 2016). This is something that needs to be considered when indicators and proxies in GBI use for assessing cities tend to rely on numeric measurements, such as census information and spatial patterns. Our findings suggest that these may indeed be understood as proxies, but that the final filter may well be the individual appraisal based on personal circumstances and capacities. This resonates with other studies that have found clear differences between the measured and perceived environment (Wang et al. 2015, Kothencz and Blaschke 2017). Our work (and others) has started to disentangle some of these relationships, but more work is needed to better understand filter (in)dependencies, and thus, how indicators and proxies may be used and, finally, alternative intervention strategies that better account for institutions and perceptions.

Developing a Transdisciplinary Approach, Insights, and Recommendations

So far, most methodological designs for studying enabling or constraining factors of GBI benefit flows in cities have been intuitive and explorative, rather than systematic and targeted (Kremer et al. 2015, Langemeyer et al. 2015, Biernacka and Kronenberg 2018). Although individually different, each case followed, more or less explicitly, a methodological design combining problem deconstruction and creation of analytical and assessment tools, assessment of the current status (e.g., misfit between supply and demand, identification of barriers), evaluation of policy or intervention options, and theorizing back through reflexive practice. Each step in the process was informed by methods selected to fit with the case-specific/contextual "problem" and available information and knowledge sources (in line with Repko and Szostak 2016). This means that even when problems are shared across case-study designs, for instance in the Barcelona and New York cases, approaches may differ depending on where relevant knowledge is needed and data are most readily available. From the initial intuitive, question-driven combination of methods, with later methods often incorporating findings or elements from previous investigations, we moved toward more systematic and targeted approaches, as in Barcelona. This was aided by knowing more about the methodological alternatives, and —in general—by previous experiences of the different teams working in these connected case studies (Kremer et al. 2015, Pauleit et al. 2019*a*).

Our case studies were motivated by the need to understand complex systems and wicked problems better, and to balance obfuscating complexity against the risk of oversimplification. Systematic guidelines and principles for how to integrate different research methods, as for example exist to some extent for MCDA (e.g., Saarikoski et al. 2016), to analyze increasingly large and complex sets of data would support further developments in this area (Dunford et al. 2018). Such guidelines would need to indicate how to select the most appropriate methods and how to bring them together (e.g., Repko and Szostak 2016, Tobi and Kampen 2018, Kronenberg and Andersson 2019, Cockburn et al. 2020) and what the alternatives might be. Furthermore, they need to identify ways to work around traditional restrictions in complex systems analyses, such as limited data access or research capacity, which is still often the reality. Developing new or adapting old ways of better understanding your system also help to more clearly highlight data, communication, and knowledge needs (e.g., Pissourios 2019, Yamagata et al. 2020) and support revised and refined methodological approaches. This is needed not least as many cities have low formal data availability (e.g., in the Global South but also in Central and Eastern Europe (Feltynowski et al. 2018)). As our methodological portfolio shows, there are alternative ways for addressing similar questions and generating synthetic, "trans-case" knowledge. Weaving together different strands of knowledge (cf. Tengö et al. 2017) may help both filling gaps and evaluating the individual contribution of also rough and potentially biased estimations (see the Barcelona case for the characteristics of GBI alternatives and capacity to provide benefits). Ultimately, we may strive to develop more archetypes, i.e., suites of methods tailored to different questions and contexts, and then continuously update these as data availability (and the need to analyze these data) changes and techniques and technology evolve.

Finally, reflexive practice and self-positioning (Cockburn et al. 2020) can play an important role in developing and revising conceptual, theoretical, and methodological understanding of complex SETS. It can act as a regulative ideal to guide transdisciplinary research on sustainability (Popa et al. 2015). In line with Popa et al.'s notion, throughout ENABLE we used such an ideal, not as a rigid methodological and normative standard or template of research design, but as a framework integrating broad epistemological and normative orientations, on the basis of which different methodological options can be envisaged (see Box 1). We argue that such a reflexive process is most useful when it can capture different dimensions of transdisciplinary efforts (see Mascarenhas et al. 2021). To fulfil that role, such reflexive practice must also acknowledge barriers known to inhibit knowledge exchange, such as cultural differences among scientists and other stakeholders (Cvitanovic et al. 2016).

CONCLUDING POINTS

The three filters framework offers flexible tools for assessment, deliberation, evaluation of flows of GBI benefits and the factors enabling or obstructing them, and a new systems perspective that generates more comparable and commensurable knowledge by pointing to linkages—be they reinforcing or disabling—between issues and approaches. Furthermore, we suggest the framework can support policy consistency and holistic strategies that bridge silos and can be helpful in enabling pathways to more successful implementation of "nature-based solutions" by systematically adapting them to local context and needs.

As applied in planning or more broadly in urban governance, we argue that the framework can do three things: (1) provide a more realistic, people–nature grounded assessment of ecosystem services and the relations between generation and demand; (2) point to interventions outside green and blue infrastructure that can change the flow and accessibility of ES and their benefits; and (3) show how you can use the filters together with ecosystem services to connect policy spheres and administrative sectors, especially by providing direct links to more "technological" spheres of planning.

The operationalization and field testing and further development of the three filters framework across cases and contexts have provided rich information and insights for revising and developing the initial framework and methodological approaches to better meet different needs. The type of information the framework generates lends itself well to in-depth questions about, for example, systems dynamics and resilience or recognition of procedural justice, as well as for assessing patterns relevant to, e.g., questions about distributional justice. The framework offers a systems-grounded approach for cross-case comparison and connecting multiple types of evidence, which is needed for the further exploration and implementation of GBI as a versatile engine for solutions to various urban wellbeing challenges.

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[1] Full project title "Enabling Green And Blue Infrastructure Potential In Complex Social–Ecological Regions: a System Approach For Assessing Local Solutions"

Responses to this article can be read online at:
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Data Availability:

All published case descriptions and analyses (the empirical basis for the case presentations in this paper) listed in an Annex. No other data, nor any code.

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APPENDIX 1. Sources (descriptions of data and methods) and contact persons for the case studies.

Case/city	Published and to be published reports
Barcelona Contact: Johannes Langemeyer (johannes.langemeyer@uab.cat), Francesc Baró (francesc.baro@uab.cat)	Langemeyer, J., D. Wedgwood, T. McPhearson, F. Baró, A. L. Madsen, and D. N. Barton. 2020. Creating urban green infrastructure where it is needed- A spatial ecosystem service-based decision analysis of green roofs in Barcelona. Science of the Total Environment 707:135487. de Luca, S., J. Langemeyer, S. Vaňo, F. Baró and E. Andersson. Adaptive resilience of and through urban ecosystem services: A trans-disciplinary approach to sustainability in Barcelona. Ecology and Society: in revision. Amorim-Maia A.T.A., F. Calcagni, J.J.T. Connolly, I. Anguelovski and J. Langemeyer. 2020. Hidden Drivers Of Social Injustice: Uncovering Unequal Cultural Ecosystem Services Behind Green Gentrification. Environmental Science and Policy 112:254-263. Baró, F., A. Calderón, J. Langemeyer and J.J.T. Connolly. 2019. Under one canopy? Assessing the distributional environmental justice implications of street tree benefits in Barcelona. Environmental Science & Policy 102, 54-64.
Halle Contact: Dagmar Haase (dagmar.haase@geo.hu-berlin.de), Manual Wolff (manuel.wolff@geo.hu-berlin.de)	Haase, D., M. Wolff and N. Schumacher. Mapping mental barriers that prevent the use of neighbourhood green spaces. Ecology and Society: in revision.
	Barber, A., D. Haase and M. Wolff. Permeability of the City - Physical Barriers of and in Urban Green Spaces in the City of Halle, Germany. Ecological Indicators: in revision. Wolff, M. 2021. Taking one step further - Advancing the measurement of green and blue infrastructure accessibility using spatial network analysis. Ecological Indicators: in press.
Lodz Contact: Jakub Kronenberg (jakub.kronenberg@uni.lodz.pl) Edyta Łaszkiewicz (edyta.laszkiewicz@uni.lodz.pl)	Biernacka, M., and J. Kronenberg. 2018. Classification of institutional barriers affecting the availability, accessibility and attractiveness of urban green spaces. Urban Forestry & Urban Greening 36: 22-33.
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Oslo Contact: David Barton (david.barton@nina.no), Zander Venter (zander.venter@nina.no)	Suárez, M., D. N. Barton, Z. Cimburova, G. M. Rusch, E. Gómez-Baggethun, and M. Onaindia. 2020. Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway. Environmental Science and Policy 108:133-143. Venter, Z., D. N. Barton, H. Figari, and M. Nowell. 2020. Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. SocArXiv papers: https://doi.org/10.31235/osf.io/kbdum.
New York Contact: Timon McPhearson (timon.mcphearson@newschool.edu), Pablo Herreros-Cantis (herrerop@newschool.edu)	Herreros-Cantis, P., V. Olivotto, Z. J. Grabowski, and T. McPhearson. 2020. Shifting landscapes of coastal flood risk: environmental (in) justice of urban change, sea level rise, and differential vulnerability in New York City. Urban Transformations 2(1):1-28. Herreros-Cantis, P. and McPhearson, T. Mapping Supply of and Demand for Ecosystem Services to Assess Environmental Justice in New York City. In review
Stockholm Contact: Sara Borgström (sara.borgstrom@abe.kth.se), Erik Andersson (erik.andersson@su.se)	Borgström, S., E. Andersson and T. Björklund. 2021. Retaining multi-functionality in a rapidly changing urban landscape - insights from a participatory, resilience thinking process in Stockholm, Sweden. Ecology and Society: in press. Borgström, S., E. Andersson and T. Björklund. Preconditions as an entry point for addressing urban multi-functionality. An investigation of nature based recreation activities in Stockholm, Sweden. In preparation.